Low-Cost Electronics Packaging Technology for Power Electronics Equipment Utilizing a Printed Circuit Board

Authors: *Yuji Shirakata** and *Kenta Fujii**

1. Introduction

Mitsubishi Electric Corporation has developed a thermal conductive power circuit assembled board (TC-PAB) technology that enables the creation of high-current printed circuit boards (PCBs) from general-purpose PCBs and the integration of magnetic components in PCBs by effectively cooling PCBs through conductive cooling. This technology, which combines various cooling element technologies, is a low-cost packaging technology that maximizes the PCB's functions, such as fixing, wiring, connection, and insulation of components.

2. PAB Technology

2.1 Background

Mitsubishi Electric has been developing a packaging technology for the main circuits of power electronics equipment using general-purpose PCBs as a base. PCBs were introduced more than half a century ago into the packaging of electronic equipment and the integration of the four key functions of fixing, wiring, connection, and insulation of components, thus significantly reducing equipment size and cost. However, the main circuits of power electronics equipment with a current of more than 50 A have remained unchanged and many components are often individually packaged. If PCBs could be applied to the main circuits of power electronics equipment, their product structure could be simplified.

2.2 Advantages of PCBs

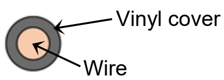
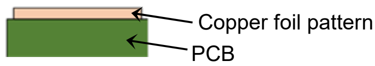
Among conventional wire connection methods, screws were widely used to fasten the wire harnesses and bus bars of mainly vinyl-covered wires. However, the development of mold-type power devices having larger capacities (50 to 75 A) has necessitated the main circuits of power electronics equipment to be constructed in PCBs.

As PCBs serve both to mutually connect and fix components, processing costs can be significantly reduced.

Table 1 compares a vinyl-covered wire and a PCB copper foil pattern. The value of the current that can flow in a conductor is restricted mainly by the temperature of the insulator. A widely-used vinyl-covered wire has a round cross-sectional surface and the ratio of surface area per unit cross-sectional area is small. In addition, such wires do not dissipate heat well due to the insulating coating and so are not suitable for high currents.

A copper foil pattern has a large surface area per unit cross-sectional area and offers excellent heat dissipation. However, it has challenges in terms of support and fixing, as well as insulation. PCBs with

Table 1 Comparison between a vinyl-covered wire and a PCB copper foil pattern

	Vinyl-covered wire	PCB copper foil pattern
Cross-sectional area	Diameter of 1 mm ≈ <u>0.79 mm²</u> 	Thickness of 35 μm × width of 22.5 mm ≈ <u>0.79 mm²</u> 
Surface area	100%	1,400%
Current	100%	370%
Characteristics	• Poor heat dissipation • Needs to be fixed • Connected by screwing • Wiring space required	• Good heat dissipation • Wire and component are fixed • Collectively assembled by soldering • Wiring space not required

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excellent heat dissipation can simultaneously solve these two challenges and so are inherently suitable for conductive components that carry high current.

2.3 Heat dissipation structure through auxiliary components

IPC-2221 and other standards provide design guidelines for copper foil patterns. However, when these standards are used for high-current copper foil patterns, wide patterns are required, which results in larger PCBs.

To solve this problem, we measured temperature data of relatively low-cost PCBs with copper foil patterns with a thickness of 70 to 105 μm using the current and pattern width as variables and defined the maximum allowable current. Furthermore, we mounted a conduction and heat dissipation auxiliary component to reduce electric resistance and suppressed the rise of temperature by increasing the heat dissipation area, thereby achieving a high current more than five times higher than that of 35-μm copper foil patterns. Subsequently, we made the design guideline into a manual. The circuit board technology having these cooling functions is called power circuit assembled board (PAB) technology.

As described above, PAB technology using conduction and heat dissipation auxiliary components enables general-purpose PCBs to be used for the main circuits of power electronics equipment with up to 100 A.

Mitsubishi Electric has been applying the PAB technology to package air conditioners, elevator control panels, induction heating (IH) cookers, and other products one after another and has been continuing to reduce their size and cost.

3. TC-PAB Technology

The PAB technology suppresses the rise in temperature by increasing the area of heat dissipation from the PCBs to the ambient air, enabling currents of up to 100 A to flow. Furthermore, Mitsubishi Electric has made copper foil patterns able to withstand even higher currents by applying conduction cooling used for chassis to PCBs.

The use of conduction cooling has enabled the integration of magnetic components, such as transformers and reactors, and semiconductor devices, such as metal-oxide-semiconductor field-effect transistors (MOSFETs), insulated-gate bipolar transistors (IGBTs), and diodes, on PCBs. These element technologies are collectively called thermal conductive PAB (TC-PAB) technology (Fig. 1).

By dissipating heat to the metal chassis, which doubles as a cooler, the temperature rise of the PCB can be reduced by 87% compared to dissipating heat only to the ambient air.

3.1 Element technologies

Figure 2 shows the packaging structure of power electronics equipment using the TC-PAB technology. The main element technologies used for this structure are described below.

3.1.1 Layer construction of PCBs

Figure 3 shows the relationship between the layer structure of PCBs and temperature rise. The temperature rise can be reduced by approximately 90% by reducing the electric resistance and thermal resistance by optimizing the layer structure. Using these technologies, a current of 150 A can be flowed in a four-

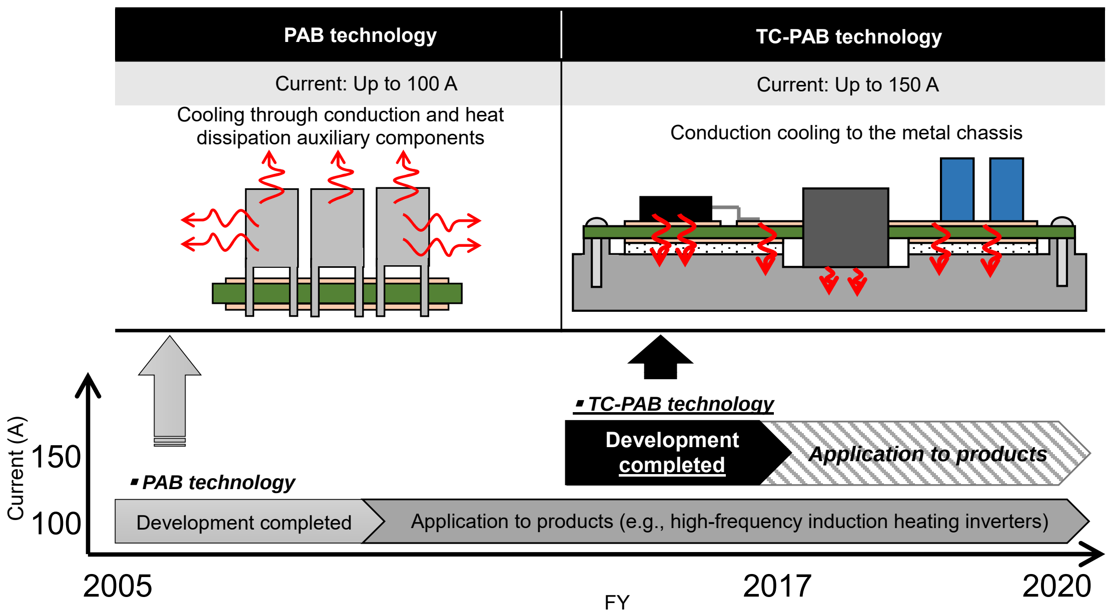


Fig. 1 Development of PAB technology and TC-PAB technology

layer PCB with a copper foil thickness of 105 μm. The design index has now been turned into a manual.

3.1.2 Method for selecting heat dissipation material

A heat conduction sheet or curable resin is used as a thermal interface material (TIM) to thermally connect the PCB and metal chassis with low heat resistance.

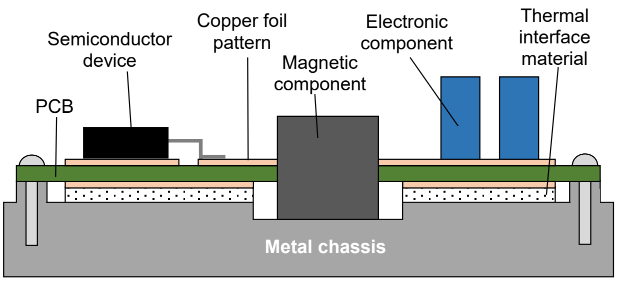


Fig. 2 Packaging structure using the TC-PAB technology

When a heat conduction sheet is used, it is necessary to judge superiority or inferiority by taking into consideration the contact heat resistance that is generated at the contact interface; hence, we developed a method that allows stable evaluation of contact thermal resistance and obtained accurate data for a variety of thermal conduction sheets as design information.

3.1.3 Cooling of semiconductor devices

To improve the heat dissipation property of surface-mounted-type semiconductor devices, we mounted a heat spreader plate (HSP), which is a high heat conduction plate material, on the back surface of a PCB at the location where the device is mounted.

Figure 4 shows the packaging structure using an HSP and its effect. In the path that transmits heat from the surface-mounted-type semiconductor device to the

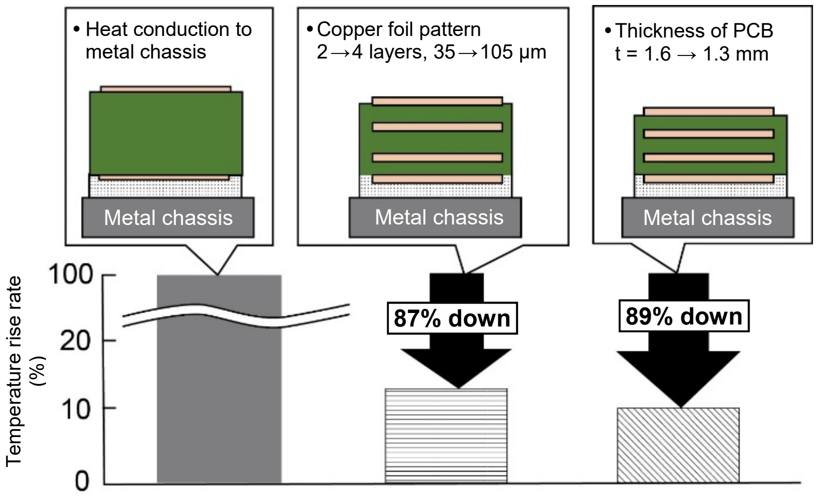


Fig. 3 Relationship between the layer structure of PCB and temperature rise

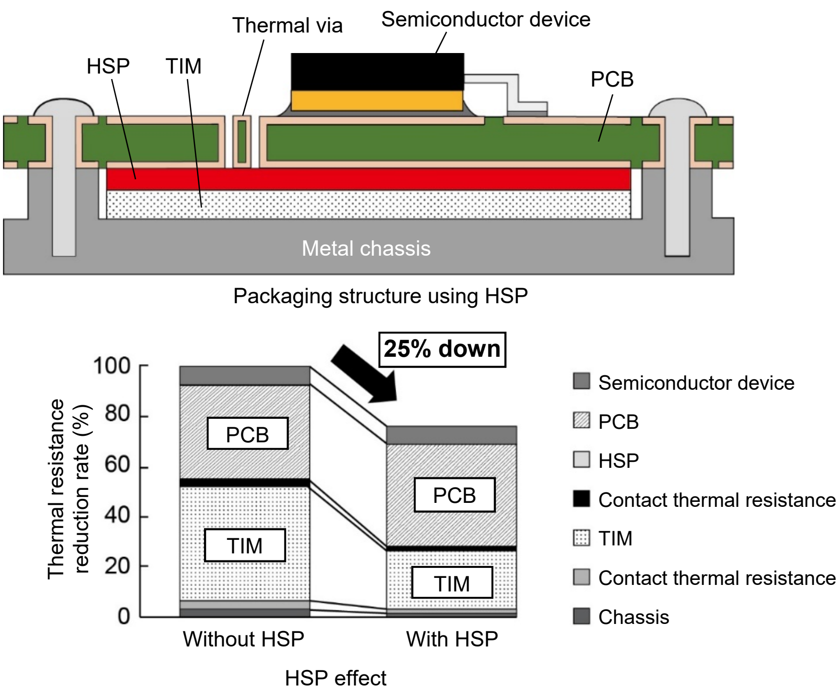


Fig. 4 Packaging structure using HSP and its effect

chassis, heat spreads in the planar direction in the HSP that has excellent heat conduction property. As a result, the cross-sectional area where heat passes the TIM expands, which reduces the thermal resistance. Thus, the HSP reduces the thermal resistance without using expensive components (e.g., copper inlay substrates).

3.1.4 Planar transformers

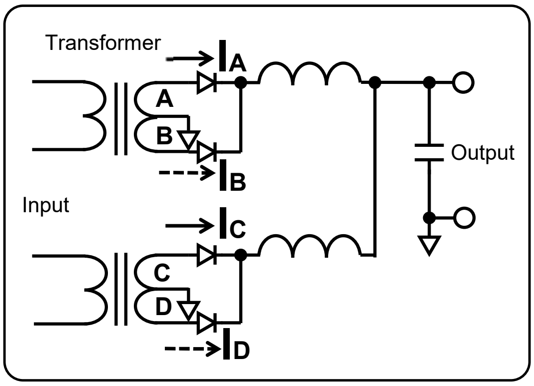
By constructing magnetic components such as transformers using a pattern coil formed on a PCB and a core that is mounted on the PCB, a miniaturized planar transformer is formed on the main circuit PCB. With the pattern at the core penetrating part, which is difficult to cool through conduction, the core is formed into an elongated shape and is divided to minimize it, thereby expanding the ratio of the pattern-exposed part and enhancing the effect of conduction cooling. In addition, an HSP is mounted on the pattern at the core penetrating part to conduct heat in the planar direction in order to effectively transport heat to the pattern-exposed part.

Furthermore, for the winding of the transformer, two circuits of the secondary winding with the minimum number of 0.5 turns are used to form a magnetic circuit (Fig. 5) to reduce the number of turns of the pattern coil, thereby reducing copper loss by approximately 40%.

3.2 Example of application to insulated step-down DC/DC converters

Figure 6 shows an example of an insulated step-down DC/DC converter, which was designed and prototyped by applying the TC-PAB technology.

The main circuit uses the insulated zero voltage switching (ZVS) method with oscillation frequency of 100 kHz and a general-purpose semiconductor device. By concentrating the main circuit components, including transformers and reactors, on the PCB, the whole main circuit is constructed on a single PCB, thereby achieving a volume of 0.5 liter (125.0 × 152.0 × 27.5 (mm)), excluding the cooler, output of 2.1 kW (14 V, 150 A), and output power density of 4.0 kW/L.



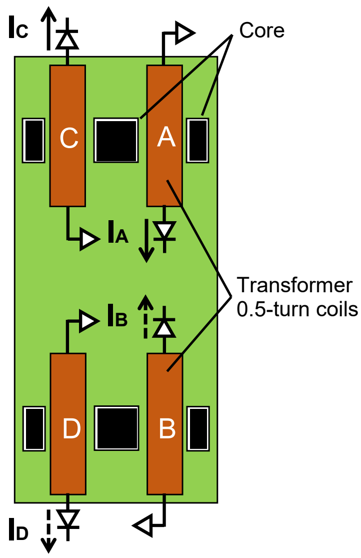


Fig. 5 Transformer coil using 0.5-turn coil

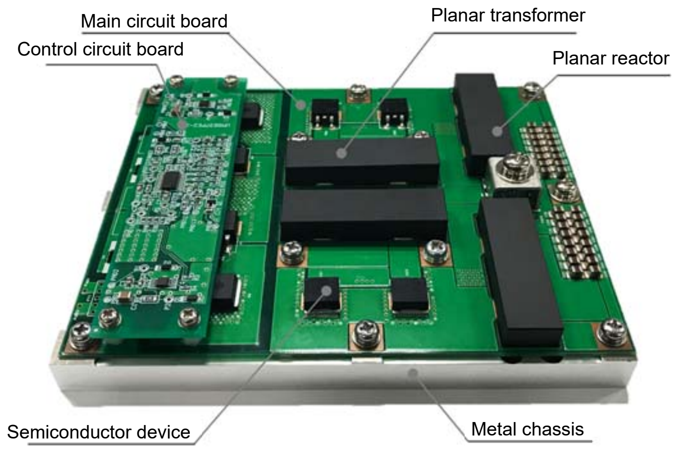


Fig. 6 Insulated step-down DC/DC converter using the TC-PAB technology

4. Conclusion

The packaging technology for electronic equipment has been improved by concentrating element functions, such as fixing, wiring, connection, insulation, and cooling of components. The PAB technology developed by Mitsubishi Electric enables a current flow of 100 A using general-purpose PCBs. Furthermore, the TC-PAB technology has integrated these element functions through conduction cooling, enabling currents of 150 A and higher to flow. We will continue to apply the technology to products.

References

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